MORE ON THE RELATIONSHIP BETWEEN WORK AND ENERGY….

With excerpts from the Physics Classroom

Internal vs External Forces

Forces may be classified as *contact forces* or *action-at-a-distance forces* (recall these from one of our first lessons on forces). Forces may also be classified as *internal forces* or *external forces.*

Internal forces are forces which, when they do work on the system, do not change the mechanical energy of the system. All these forces do is to cause the energy to be changed from kinetic to potential or vice-versa. Such forces include gravitational forces, elastic forces, magnetic and electrostatic forces.

External forces, you guessed it, *change the mechanical energy of the system.* Examples of such forces include, but are not limited to, applied forces, frictional forces, tensions, etc. When such forces do work on a system, they either add energy (do positive work) or remove energy (do negative work) to/from the system. In doing so, they cause the mechanical energy of the system to change. The gain or loss of energy can be in the form of kinetic energy, potential energy, or both.

It is important that you be able to visualize the situation rather than just put numbers into an equation and plug and chug. To assist you, several scenarios are presented below. These all involve *internal forces*. Is mechanical energy conserved? ___________

For each of the scenarios, indicate whether the energy is changed from kinetic energy to potential energy or vice versa.

Example 1 *A ball is dropped from a height of 2.0 m in the absence of air resistance.*

Example 2 *A skier glides from the top of a mountain to its base and then up another hill on a frictionless surface.*

Example 3 *A baseball is travelling upwards towards a man in the bleachers (again ignore friction – these are all scenarios involving internal forces)*

Example 4 *A bungee cord begins to exert an upward force on a bungee jumper*

Example 5 *A spring in a dart gun exerts a horizontal force on the dart as it is launched from its initial rest position*

The following scenarios involve *external forces.* Is mechanical energy conserved? ________ For each of the scenarios presented, indicated whether positive work or negative work was done by the force in question and then indicate whether the work changed the kinetic energy, potential energy, or both for the system studied.

Example 6 *A badminton player hits an awesome forehand. The racket is moving horizontally as the strings strike the birdie.*

Example 7 *A golfer makes contact with a golf ball resting on a tee. The golf club exerts a force at a 10° angle above the horizontal.*

Example 8 *Rusty Nales pounds a nail into the wall. The hammer is moving horizontally on contact with the nail.*

Example 9 *The frictional force between the tires and the road surface pushes back on a skidding car.*

Example 10 *A swimmer experiences a horizontal reaction force as she pushes on the blocks at the start of the race.*

Example 11 *Alex applies a force to lift a barbell above his head at a constant speed. Consider only the portion while the object is in motion.*

The above examples analyzed what was happening from a qualitative point of view. The quantitative relationship between work and energy is an expansion of the concept developed yesterday:

$$M.E._{BEFORE} + W_{EXTERNAL} = M.E._{AFTER}$$

In this expression, if only *internal forces* are at play, then no work is done and the equation simplifies to that given yesterday. If *external forces* are at play, then one must consider the work done.

Consider the example of Alex lifting a barbell. Let's assume that he is holding the barbell just below his waist. The barbell *weighs* 1000 N and, at this point is 1.0 m above the ground. At this moment, what is the gravitational potential energy of the barbell? _________ What is the kinetic energy of the barbell? _________ Now, as he lifts the barbell at a constant velocity over a distance of 0.50 m to a point above his head, what work has he done? If you have said 500 J then you are correct (call me over if you did not obtain this answer). To determine the mechanical energy of the system at this point:

$$M.E._{BEFORE} + W_{EXTERNAL} = M.E._{AFTER}$$

$$E_g + E_k + W_{EXTERNAL} = M.E._{AFTER}$$

$$mgh + 0 + F\Delta d = M.E._{AFTER}$$

$$1000(1) + 0 + 1000(0.5) = M.E._{AFTER}$$

$$1500 \text{ J} = M.E._{AFTER}$$

At the moment that the barbell is above his head, the barbell is at rest. The 1500 J of $M.E._{AFTER}$ is thus the gravitational potential energy that the barbell has at this moment.

Consider a car of mass 1000 kg moving along a horizontal road surface at 30 m/s. The brakes are applied and the car skids over a distance of 20 m while a force of friction of 8000 N is experienced. What will be the car's speed at the end of the 20 m?

$$M.E._{BEFORE} + W_{EXTERNAL} = M.E._{AFTER}$$

$$E_g + E_k + W_{EXTERNAL} = E_g' + E_k'$$

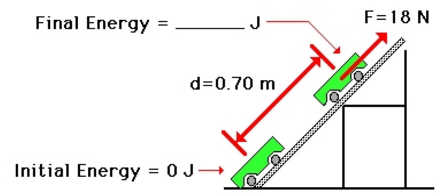
$$0 + \tfrac{1}{2}mv^2 + F\Delta d = 0 + \tfrac{1}{2}mv^{2\,\prime}$$

$$\tfrac{1}{2}(1000)(30)^2 + (-8000)(20) = \tfrac{1}{2}(1000)v^{2\,\prime}$$

$$450000 - 160000 = 500v^{2\,\prime}$$

$$v' = 24.1 \text{ m/s}$$

As a final example, consider a cart being pulled up an inclined plane at constant speed by a student. The applied force on the cart (say 18 N) is directed parallel to the incline. The cart is displaced parallel to the incline over a distance of 0.70 m. The cart was initially at rest.



What is the initial mechanical energy of the cart?
E_g = 0 J and E_k = 0 J. Thus ME_{BEFORE} = 0 J.

How much work was done by the applied force?
$W = F\Delta d\cos\theta = 18(0.70)\cos 0° = 12.6$ J

What is the mechanical energy of the car in the end?

$$M.E._{BEFORE} + W_{EXTERNAL} = M.E._{AFTER}$$
$$0 + 12.6 = M.E._{AFTER}$$

$$M.E._{AFTER} = 12.6 \text{ J}$$

If the car is still moving at this point, then the 12.6 J represents a combination of E_g and E_k. If the car is at rest, then the 12.6 J is simply the car's E_g at this point.

The work-energy relationship presented here is useful to solve complex problems. Like all complex problems, they can be made *simple* if first analyzed from a conceptual viewpoint and broken down into parts. In other words, avoid treating work-energy problems as mere mathematical problems. Rather, engage your mind and utilize your understanding of physics concepts to approach the problem. Ask "What forms of energy are present before and after?" and "Based on the equations, how much of each form of energy is present before and after?" Ask "Is work being done by external forces?" Use this approach on the following practice problems.

1. A 1000 kg car travelling at a speed of 25 m/s skids to a stop. The car experiences 8000 N of friction. Determine the stopping distance of the car.

   (39.1 m)

2. At the end of a roller coaster ride, the 6000 kg train (cars and passengers) is slowed from a speed of 20 m/s to a speed of 5 m/s over a distance of 20 m. Determine the braking force required.

   (- 56 250 N)

3. A shopping cart full of groceries is sitting at the top of a 2.9 m high hill. The cart begins to roll down the hill onto the horizontal road surface. For simplicity, consider all the surfaces frictionless. A can of peaches is inside the cart and, with respect to the ground, is located 0.9 m above the ground. The cart then hits a stump and, on impact, the 250 g can of peaches flies horizontally out of the shopping cart. The can strikes the car horizontally with an average force of 500 N. How deep a dent is made in the car?

   (9.8 mm)

4. A 1248 kg car is moving at 68.5 km/h. How much thermal energy is lost through friction in the brake linings as the car comes to a stop?

5. A 1.87 kg ball hangs from the ceiling at the end of a string that is 1.55 m long. The ceiling height is 3.24 m. What is the gravitational potential energy of the ball relative to the floor and what will be the speed of the ball on impact if the string is cut?

6. A 1900 kg car moves down a level highway under the action of two forces. One is a forward force on the car of 1309 N from the motor; the other is a frictional force of 772 N. What is the speed of the car after it has moved a distance of 18.6 m assuming that it had an initial speed of 1.0 m/s?

7. A 7.86 kg sled is given a kick on a frozen pond, imparting to it an initial speed of 1.92 m/s. The coefficient of friction between the sled and the ice is 0.14. Use the work-energy theorem to determine how far the sled moves before:
   a. reaching a speed of 1.0 m/s and,
   b. coming to rest.

8. A 20 kg child is in a swing attached to ropes which are 2.3 m long.
   a. Find the gravitational potential energy of the child, relative to the lowest point in the swing, if the swing is pulled back such that the ropes make an angle of 30° to the vertical.
   b. Determine the speed of the child at the lowest point in the swing.

9. Pete Zaria applies a rightward force of 1.37 N over a distance of 0.575 m to set a 656 g root beer mug from rest into motion along a level countertop. Determine the kinetic energy of the mug after Pete is done pushing it.

10. A car moving at 50 km/h skids, with its brakes locked, to a complete stop over a distance of 15 m. What would be its stopping distance if the initial speed was 150 km/h?

11. A 47.0 g golf ball is driven from the tee with an initial velocity of 52.0 m/s. It's flight path is parabolic in nature, with the maximum height attained being 25 m.
    a. What is the ball's speed at the maximum height? *(Hint: it is not 0 m/s)*
    b. What is the speed of the ball when it is 10.0 m below its maximum height?

12. A jet fighter is launched from an aircraft carrier with the aid of its own engines and a steam-powered catapult. The engines provide a thrust force of 180000 N. In being launched from rest, it moves through a distance of 87 m and has a kinetic energy of 4.7×10^7 J at take-off.
    a. How much work is done by the catapult?
    b. What was the average force exerted by the catapult during take-off?

13. A grade 9 student is playing with a bead that slides on a wire as shown. The wire and the bead are frictionless but the sheathing at the end of the wire exerts a constant frictional force on the 5.0 g bead. If the sheathing is 10 cm long, determine the magnitude of the frictional force.